Open Research Online

The Open University's repository of research publications
and other research outputs

Metal in lunar meteorite North West Africa 10989 Insight into survivability of impactor material delivered to the Moon

Conference or Workshop Item

How to cite:

Morland, Zoe; Joy, Katherine; Gholinia, A and Degli Alessandrini, Giulia (2019). Metal in lunar meteorite North West Africa 10989 Insight into survivability of impactor material delivered to the Moon. In: Lunar and Planetary Science Conference, 18-22 Mar 2019, Houston, USA.

For guidance on citations see FAQs.

© 2019 Zoe Morland; 2019 Katherine Joy; 2019 A. Gholinia; 2019 Giulia Degli Alessandrini

https://creativecommons.org/licenses/by-nc-nd/4.0/

Version: Version of Record

Link(s) to article on publisher's website:
https://www.hou.usra.edu/meetings/lpsc2019/

Copyright and Moral Rights for the articles on this site are retained by the individual authors and/or other copyright owners. For more information on Open Research Online's data policy on reuse of materials please consult the policies page.

oro.open.ac.uk

METAL IN LUNAR METEORITE NORTH WEST AFRICA 10989: INSIGHT INTO SURVIVABILITY OF IMPACTOR MATERIAL DELIVERED TO THE MOON.

Z. S. Morland[1,2], K. H. Joy[2], A. Gholinia[3] and G. Degli Alessandrini[1]. [1]School of Physical Sciences, Open University, Milton Keynes, UK., [2]School of Earth and Environmental Sciences, University of Manchester, UK. [3]School of Materials, University of Manchester, UK.
Corresponding email: zoe.morland@open.ac.uk

Introduction: Lunar meteorites derive from material ejected at escape velocity from impact events on the Moon. The ejected material is subsequently caught by Earth's gravitational field and falls to the ground as a meteorite [1]. Analysis of lunar meteorites improves understanding of the whole surface of the Moon, not just areas visited by the Apollo missions [2]. Moreover, they unlock crucial insight into dynamical processes that have affected the inner Solar System [3]. Despite recent investigation, the impact flux and composition of impactor material delivered to the inner Solar System throughout history still remains enigmatic [4,5]. Here we investigate a newly discovered lunar meteorite to see if it holds preserved impactor material derived from an asteroid projectile and investigate how such material has been altered by the impact process and subsequent regolith revolution.

Samples and Methods: North West Africa (NWA) 10989 is a lunar regolith breccia, formed within a few meters of the lunar surface. It represents the fusion of an ancient regolith soil that was composed of highland with a minor component of basaltic rocks. The 1 cm sized fragment of NWA 10989 we investigated specifically contains highland granulites, glassy impact melt breccias (GIMBs), clast-rich impact melt breccias (CIMBs), monomineralic pyroxene and rare mare basalt fragments. These clasts are held within a glassy matrix that includes impact melt spherules and Fe-Ni metal. The Fe-Ni metal is dominantly contained within a single 1.90 × 0.85 mm grain along with several other smaller grains and abundant fine particles in the matrix (Figs. 1 A & B).

At the University of Manchester, the following instruments were used to investigate the sample's mineralogy and chemistry: (1) an ESEM to obtain close-up back scattered electron (BSE) and whole sample BSE merger images, qualitative compositional energy-dispersive X-ray spectroscopy point spectra, and whole sample elemental map using the EDAX EDS detector; (2) a Raman spectrometer to identify Fe-oxide phases; (3) an Electron Microprobe Analyser to quantitatively measure major element concentrations; (4) a broad-ion beam (Argon) mill to polish; and (5) an Oxford Instruments Electron Backscatter Diffraction system with AZtec software to study the crystallographic structure of the metal components.

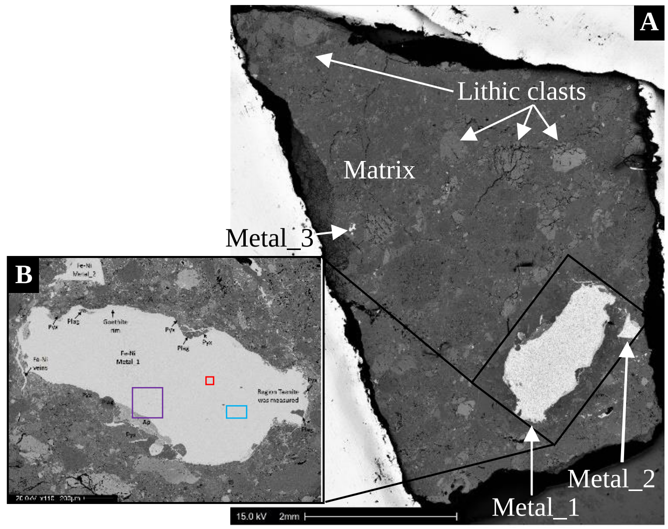

Figure 1: *(A)* Whole sample BSE image – metallic grains clearly distinguishable as white grains, with the metal grain (labelled Metal_1) of interest in the lower middle right measuring 1.90 × 0.85 mm in size. *(B)* Metal_1 close-up BSE image. Labels identify the associated silicates around the edge and the taenitic region detected within the metal. The edge of the metal fragment has been oxidized to the mineral goethite when it was in the terrestrial desert. The squares indicate where EBSD was used (Fig. 3)

Results: The metallic grain is composed of predominantly kamacite (low-Ni) with minor amounts of taenitic (high-Ni) material and K-rich schreibersite. The kamacite metal itself has slightly elevated levels of K (0.16-0.22 wt%). Comparing the composition of this metal to the meteoritic field (Fig. 2 A) suggests that the metal is similar to asteroid-derived meteorite groups, and thus could indicate and exogenous origin [6]. However, the silicates (equilibrated olivine, pyroxene [pyx] and plagioclase [plag]) which surround the metal fragment and are enclosed within it, reflect endogenous lunar compositions (Fig. 2 B). This presents a dichotomy in which the metal appears to not be native to the Moon, but it is enclosed within a silicate matrix that is lunar-like.

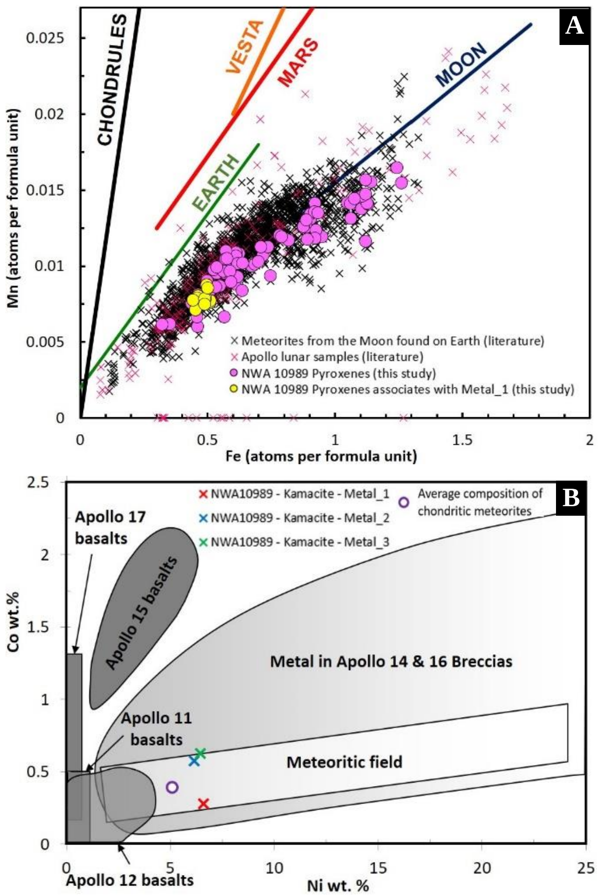

Figure 2: *(A)* NWA 10989 metallic grain plotting within the meteoritic field, *(B)* Pyroxene grains in contact with the metallic grain showing their native lunar composition rather than meteoritic.

Impact modification: We suggest that the large metal fragment represents material delivered to the Moon as a projectile. The impact process involved either (i) a relatively intact piece of meteorite debris that survived the collisional process to be mixed as a complete fragment into a silicate impact melt sheet, or (ii) a projectile was vaporized and chemically mixed into a lunar impact melt sheet that then crystallized precipitating out metal as an accessory phase. The elevated K-content of the kamacitic component could support the latter suggestion, if the K were scavenged from KREEP-bearing lunar target rocks during the impact melt sheet formation stage.

The complex boundary of Metal_1 (Fig. 1 B) exhibits an interaction zone between the metal grain and both the associated silicate clasts and surrounding silicate regolithic matrix. This, along with the composition dichotomy between silicates and metal, suggest that the metal fragment may have undergone multiple stages of reprocessing, brecciation and crystal plastic deformation during its time on the lunar surface.

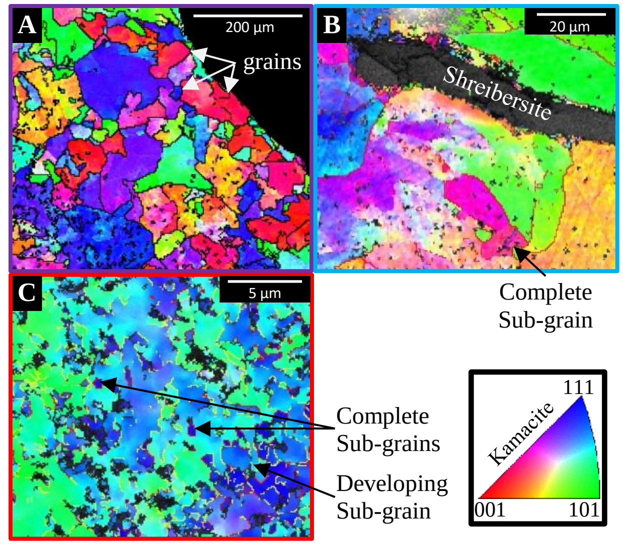

Figure 3: Inverse pole figures of parts of Metal_1, indicated in Fig. 1 B. Different colours indicate different lattice orientations parallel to a reference direction, as specified by the triangle colour key. In *(A)*, black lines denote regions with misorientations >15º. In (*B)* & *(C)*, red and yellow lines denote regions with misorientation >10º and >3º respectively.

EBSD reveals the metal's internal microstructure to be an aggregate of variably orientated grains 50-150 µm in size (Fig. 3 A & B). Colour gradients indicate gradual variations in lattice orientation, suggesting crystal lattice bending. Moreover, subgrains have also been recognized as different coloured regions signified by sharp low-angle misorientations (Fig. 3 B & C, subgrain boundaries in red and yellow). This suggests that the metal has undergone crystal plastic deformation induced by strain from reprocessing.

Implications: Study of this material will improve our understanding of the nature and budgets of lunar metal in the lunar regolith, and help us understand how metal is precipitated out of and processed within impact melt deposits. This will aid forthcoming assessments of the Moon's potential as a resource [7], which is important for future lunar exploration plans and in-situ resource utilization (ISRU) of the lunar surface.

Acknowledgements: Thanks to Martin Goff, for donating the sample.

References: [1] Korotev R. L. (2005) *Chem Erde, 65(4),* 297-346. [2] Jolliff B. L. et al. (2000) *JGR, 105,* 4197-4216. [3] Calzada-Diaz A. et al. (2015) *Meteorit. Planet. Sci.*, *50,* 214-228. [4] Hartmann W. et al. (2000) In: R. Canup and K. Righter, eds. *Tuscon: University of Arizona Press,* 805-826. [5] Joy K. H. (2012) *Science, 336(6087)*, 1426-1429. [6] Goldstein J. I. and Yakowitz H. (1971) *P. Lunar. Plant. Sci., 2,* 177-191. [7] Crawford I. A. (2015) *Prog. Phys. Geog. 39(2),* 137-167.